Ambient Groundwater Quality of the Virgin River Basin:

A 1997 Baseline Study

Prepared by

Hydrologic Support and Assessment Section
Water Quality Division
Arizona Department of Environmental Quality

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ABSTRACT

The Groundwater Monitoring Unit of the Arizona Department of Environmental Quality (ADEQ) completed a baseline groundwater quality study of the Virgin River Groundwater Basin (VRGB) in 1997. Located in the arid northwest corner of Arizona, the VRGB consists mainly of undeveloped public lands punctuated by small areas of private land, some of which contain densely-settled residences utilizing septic systems for wastewater treatment. A total of 38 groundwater samples were collected for the study including 33 stratified random samples from four aquifers: Beaver Dam, Littlefield, Virgin River alluvial, and Virgin River basin. All groundwater samples were analyzed for Safe Drinking Water (SDW) inorganics, 10 samples were analyzed for radionuclides, and 3 samples were analyzed for Groundwater Protection List (GWPL) pesticides. Laboratory results revealed no detections of GWPL pesticides, while only one radionuclide sample exceeded the Primary Maximum Contaminant Levels (MCLs) for gross alpha. Inorganic parameter levels of the VRGB samples did not exceed any health-based Primary MCLs, though aesthetics-based Secondary MCLs for chloride, iron, manganese, field pH, sulfate, and total dissolved solids were exceeded, especially in the Littlefield and Virgin River alluvial aquifers. These results suggest that regional groundwater quality conditions generally support drinking water uses; however, some residents may prefer to use treated water for domestic purposes because of aesthetic reasons.

Piper trilinear diagrams revealed each aquifer in the VRGB had a characteristic water chemistry: Beaver Dam aquifer had bicarbonate-calcium water, Littlefield and Virgin River alluvial aquifers had sulfate-calcium water, and Virgin River basin aquifer had a mixed water chemistry. Statistical analyses indicated that many significant differences exist in groundwater quality parameter levels among aquifers in the VRGB. Generally, inorganic parameters in the Littlefield and Virgin River alluvial aquifers have significantly higher levels than the Beaver Dam and Virgin River basin aquifers.

A strong correlation existed among the levels of most groundwater quality parameters in the VRGB, perhaps indicating a common natural source for most parameters. Exceptions to this trend include nitrate, fluoride, iron, and manganese; parameters which may come from other natural or cultural sources. There is also a significant relationship between decreasing groundwater quality parameter levels and increasing groundwater depth below land surface in the VRGB; however, when examined by individual aquifer few of these statistical relationships are present. Thus, these VRGB depth-dependent parameter levels may be more the result of parameter level differences among aquifers and the accompanying groundwater depth variations than by any actual relationships within aquifers.

The groundwater quality of the Beaver Dam and Littlefield aquifers may be impacted by cultural factors as evidenced by the comparison of upgradient, control samples to the 95% confidence interval established for each aquifer. The presence of poorer-quality groundwater beneath the Beaver Dam aquifer and better-quality groundwater beneath the Virgin River alluvial aquifer was also indicated by results of limited sampling of deeper aquifers.

OBJECTIVES

The Groundwater Monitoring Unit (GMU) of the Arizona Department of Environmental Quality (ADEQ) conducted an extensive regional groundwater quality study of the Virgin River Groundwater Basin (VRGB) in 1997. The impetus for this groundwater study was fourfold:

< Requests by both the Northern Regional Office (NRO) of ADEQ and Mohave County, Arizona for additional groundwater quality data in the VRGB because of groundwater contamination concerns from septic systems;

< An ADEQ report (Hood, 1991) which, in evaluating the need for ambient monitoring in each of the 50 designated groundwater basins in Arizona, noted a lack of groundwater quality data collection alternatives in the VRGB such as public water systems and other organizations collecting groundwater quality data;

< Because of recent population growth and the associated increase in well drilling in the previously sparsely-populated VRGB, an opportunity to collect groundwater samples from areas that could not be sampled by prior studies;

< The opportunity to conduct a baseline groundwater quality study in a relatively undeveloped area before explosive population growth in the VRGB; and

This groundwater study had four objectives:

< To obtain baseline data throughout the VRGB on the occurrence, concentrations, and ranges of a wide variety of groundwater quality parameters including the identification and delineation of any areas with groundwater quality problems.

< With the sampling sites determined through means of stratified random selection, to examine aquifers within the VRGB for statistically significant groundwater quality differences.

< Using the sampling sites determined through means of stratified random selection, examine relationships with groundwater quality parameter levels and indices such as groundwater depth and other groundwater quality parameter levels.

< To establish a statistically designed ambient groundwater quality index well monitoring network for the VRGB.

Meeting these objectives in a reproducible, scientific study that utilizes statistical analysis to make broad statements concerning groundwater quality will provide many benefits, some of which are listed below:

- Residents in the VRGB utilizing water supplied by a public water system for domestic purposes have the assurance that this resource is tested regularly and meets water quality standards set by the Safe Drinking Water (SDW) Act. However, many rural residents are served by private wells whose water is usually not tested for a wide array of possible pollutants. Although Arizona statutes require well drilling contractors to disinfect new wells, which are used for human consumption, for potential bacteria contamination, many wells are not further tested for other types of groundwater quality problems. Thus, contamination affecting groundwater pumped from private wells may go undetected for years and have adverse health effects on users of this resource. Collecting and analyzing groundwater samples from all these private wells would be prohibitively expensive. However, a statistically-based ambient groundwater study to estimate groundwater quality conditions on a regional scale and identify possible associations with landscape attributes to help explain impaired groundwater conditions offers an affordable alternative.

- Determining whether groundwater in the VRGB is currently suitable for domestic uses;

- Determining whether septic system effluent has impacted groundwater quality in the VRGB, especially at groundwater depths at which domestic wells are commonly perforated. Levels of nitrate, considered the most important septage indicator, will be an important factor in making this determination;

- Provides a scientific basis for distinguishing pollution impacts to aquifers;

- Assessing the effectiveness of groundwater protection efforts such as industry Best Management Practices (BMPs) by tracking groundwater quality changes;

- Be a useful tool with which to guide VRGB planning such as construction of new public water supply well locations and determination of wellhead protection areas.

CONCLUSION

This 1997 ADEQ regional study to assess the groundwater quality of the VRGB had four major objectives: obtain baseline data throughout the basin, examine groundwater quality differences between various aquifers, examine relationships with groundwater quality parameter levels and indices such as groundwater depth and other groundwater quality parameter levels, and establish an ambient monitoring index well network. The results of the study indicated the following key findings for each objective:

A) Obtain baseline data on the occurrence, concentrations, and ranges of a wide-array of groundwater quality parameters:

< Generally groundwater quality in the VRGB meets SDW standards and is acceptable for drinking and other domestic uses. Some residents, however, prefer to use treated or filtered water because of poor aesthetic characteristics (taste, smell, and/or color) of the groundwater. The Littlefield and Virgin River alluvial aquifers are especially saline and this discourages their more extensive use as a water supply.

< There were no exceedances of any health-based, inorganic Primary MCLs in the 38 groundwater samples that were collected and analyzed in the VRGB. The samples were tested for 10 inorganic parameters (see **Figure 5**).

< There were many aesthetics-based, inorganic Secondary MCL exceedances in the 38 groundwater samples. Of the 10 inorganic parameters having Secondary MCLs, the following exceedances occurred: Cl - 15, Fe - 7, Mn - 5, pH-field - 1, SO_4 - 17, and TDS - 25 (see **Table 2** and **Figure 6**). The majority of the exceedances occurred in samples from the Littlefield and Virgin River alluvial aquifers.

< The potential for currently-registered pesticides to contaminate the groundwater was also a component of this study. As a result, groundwater samples were collected in areas of agricultural activity for GWPL analysis. This analysis consists of the 152 pesticides used in Arizona that are considered most likely to leach to the groundwater through normal agricultural use (see **Appendix H**). There were no detections of any pesticides in the samples tested (see **Appendix G**).

< Radionuclide levels in groundwater were also examined in this study. Ten samples were analyzed for gross alpha, radium-226, and radium-228. Only one sample from the Littlefield aquifer exceeded the gross alpha Primary MCL (see **Appendix F**).

B) Examine groundwater quality differences among various aquifers:

< Previous groundwater studies indicated the existence of four aquifers within the VRGB: Beaver Dam, Littlefield, Muddy Creek, and a single Virgin River aquifer. This study was unable to locate any wells in Arizona to sample that tapped the Muddy Creek aquifer. Based on groundwater sampling conducted for this study, the Virgin River aquifer appears to consist of not one but two distinct aquifers - an alluvial and basin. The Virgin River alluvial aquifer consists of floodplain deposits generally located north of the Virgin River while the Virgin River basin aquifer consists of alluvial-fan deposits generally located south of the Virgin River.

< Piper trilinear diagrams reveal the groundwater chemistry in the VRGB varies greatly between aquifers, with each aquifer having a distinctive chemical fingerprint. Groundwater samples collected from the Beaver Dam aquifer exhibit a mixed water chemistry of the $Ca\text{-}HCO_3$ type, with samples to the east of Beaver Dam Wash tending towards higher SO_4 concentrations. Groundwater samples from Littlefield and Virgin River alluvial aquifers exhibit a very consistent $Ca\text{-}SO_4$ water chemistry as did the deep groundwater sample collected from beneath the Beaver Dam aquifer. Groundwater samples collected from the Virgin River basin aquifer exhibit a clustered pattern with a mixed water chemistry of $Na\text{-}SO_4$, $Na\text{-}HCO_3$, and $Ca\text{-}HCO_3$ varieties while the water chemistry of the two deep samples collected from beneath the Virgin River alluvial aquifer were Na-Cl and $Na\text{-}HCO_3$ (see **Table 1** and **Figure 4**).

< The variation in groundwater quality parameter levels was assessed among four aquifers in the VRGB: Beaver Dam Wash, Littlefield, Virgin River alluvial, and Virgin River basin. Statistical results indicate numerous significant differences exist in the levels of groundwater quality parameters in the four aquifers. Many inorganic parameters, especially major ions, in the Littlefield and Virgin River alluvial aquifers have significantly higher levels than those in the Beaver Dam and Virgin River basin aquifers. Other interesting patterns include: temperature - field was significantly lower in those aquifers having a direct contact with perennial surface water flow (Beaver Dam and Virgin River alluvial), and nitrate was significantly lower in the Littlefield aquifer than the other three aquifers (see **Table 4**).

< Two groundwater samples collected from great depths in the Virgin River alluvial aquifer and one from beneath the Beaver Dam aquifer appear to be tapping deeper aquifers of different groundwater quality than the surficial aquifers. The groundwater quality parameter levels associated with these deep samples were compared with the corresponding 95% Confidence Intervals established for the respective aquifers. Results indicate the deep Beaver Dam aquifer parameter levels were frequently above the upper 95% Confidence Interval while the deep Virgin River alluvial parameter levels were frequently below the lower 95% Confidence Interval. Thus, the Beaver Dam aquifer appears to have lower groundwater quality parameter levels than the deep Beaver Dam aquifer sample; in contrast, the Virgin River alluvial aquifer appears to have higher groundwater quality parameter levels than the deeper Virgin River

alluvial aquifer
(see **Table 15**).

< Groundwater quality parameter levels of an upgradient, control sample were compared to the 95% Confidence Intervals established for each respective aquifer. The results indicate that the control samples for the Beaver Dam and Littlefield aquifers were often below the lower 95% Confidence Interval, indicating the groundwater quality of these aquifers may already be impacted by residential and commercial development (see **Table 14**).

C) Examine relationships with groundwater quality parameter levels and indices such as groundwater depth and other groundwater quality parameter levels:

< The levels of most groundwater quality parameter levels in the VRGB are statistically strongly correlated, probably indicating a common natural source for most parameters. Exceptions to this trend include F, temperature-field, and turbidity, which seldom had significant correlations; pH and nitrate had negative correlations in which these parameter levels tended to decrease as other groundwater quality parameter levels tended to increase. This may indicate that nitrate is from a different source than other parameters and may be related to human activities (see **Table 5** thru **Table 9**).

< Decreasing levels of numerous groundwater quality parameters are also significantly related to increasing groundwater depth below land surface in the VRGB. Few of these statistical relationships are present when individual aquifers are examined. Thus, these VRGB parameter level - groundwater depth relationships may be influenced more by differences in average parameter level and groundwater depth between aquifers than any actual relationship within aquifers (see **Table 10**, **Table 11**, **Table 12**, and **Table 13**).

D) Establish an ambient groundwater monitoring well network in the VRGB:

< An ambient groundwater monitoring well network of 16 index wells was established in the VRGB. The wells follow a statistical-design with equal numbers of wells located in the four distinct aquifers. One well in each aquifer was designated a "control" well and located upgradient of residential and commercial development as much as possible. With the rapid population growth in the VRGB, a qualitative estimation is that resampling of the index wells should occur in a five-year intervals based on studies conducted by the Ambient Groundwater Monitoring Program in other areas of Arizona (see **Figure 8** and **Table 16**).

DISCUSSION AND RECOMMENDATIONS

There were 2 major findings in this ADEQ VRGB groundwater quality study:

< Although prior literature (Black and Rascona, 1981) stated that there was 1 Virgin River aquifer, the data from this study suggests the Virgin River aquifer actually consists of 2 distinct aquifers with very different groundwater quality characteristics. These 2 aquifers are referred to in this study as the Virgin River alluvial aquifer and the Virgin River basin aquifer. This distinction was made on the basis of dissimilar groundwater quality chemistries and significantly different groundwater quality parameter levels.

< The four VRGB sampled aquifers - Beaver Dam, Littlefield, Virgin River alluvial, and Virgin River basin - have very dissimilar groundwater quality conditions. These groundwater quality differences appear to stem from localized hydrologic and geologic conditions within the aquifers.

Hydrologic conditions seem to be the chief factor affecting the groundwater quality in the Beaver Dam and Virgin River alluvial aquifers. The relatively low groundwater quality parameter levels reflective of the Beaver Dam aquifer are likely the result of recharge by good-quality surface water along the length of Beaver Dam Wash (Black and Rascona, 1991). Surface water quality also seems to be a major factor in the groundwater quality of the Virgin River alluvial aquifer. The relatively high groundwater quality parameter levels characteristic of the Virgin River alluvial aquifer are probably due to recharge by highly saline surface water along the length of the Virgin River. Factors influencing the poor-quality surface water in the Virgin River, which overlies the Virgin River alluvial aquifer, include an initial high concentration of salt, spring discharges around Littlefield, and irrigation returns (Black and Rascona, 1991).

In contrast, geologic conditions seem to be the main influence impacting groundwater quality of the Littlefield and Virgin River basin aquifers. The relatively high groundwater quality parameter levels found in the Littlefield aquifer could be due to groundwater contact with limestone known as the "Littlefield Formation" (Meissner Engineers, 1960). This flat-lying, fresh-water limestone unit is overlain by the alluvial fan deposits and is the likely cause of the high Ca levels found in the Littlefield aquifer groundwater. Recharge from the Virgin Mountains is thought to largely dictate the groundwater quality of the Virgin River basin aquifer. The Virgin Mountains consist primarily of granite and sedimentary rocks and recharge through these formations seems to yield water of generally potable quality.

Although regional groundwater quality conditions support drinking water uses in the VRGB, there are several indications that groundwater quality in the area should be closely monitored to avoid future problems. Of particular concern is the impact of the many recently-constructed residences and their use of septic systems for wastewater treatment. Although nitrate is present at only low levels in the

VRGB, this parameter exhibits several unique patterns. Judging from parameter level correlations, nitrate appears to stem from a different source - perhaps septic systems - than most other parameters. Nitrate levels in areas of residential development overlaying the Beaver Dam and Littlefield aquifers are elevated when compared to upgradient, control samples. Nitrate levels in the Beaver Dam, Virgin River alluvial, and Virgin River basin aquifers are significantly higher than those in the Littlefield aquifer, contrary to the patterns of other groundwater quality parameters. Despite these trends, nitrate levels do not currently pose a problem as the highest sampled nitrate (as N) level was 5.4 mg/l, approximately half the 10.0 mg/l Primary MCL although nitrate (as N) levels above 3 mg/l are thought to be an indicator of land use impacts (Madison and Brunett, 1984). Nevertheless, the previously-mentioned patterns illustrate the need to closely monitor nitrate levels in the VRGB.

Because of the report’ s scope and timing, this study is a valuable foundation upon which to build future groundwater quality monitoring efforts in the VRGB. Previous groundwater quality studies by the USGS in 1976 and ADWR in 1991 had very limited numbers of groundwater samples subjected to detailed chemical analysis. In the intervening period of time, rapid, clustered population growth occurred in this relatively-undeveloped area. This growth allowed for a much larger number of wells located over a greater spatial expanse in which to sample for this report. Thus, the greater comprehensiveness of this study should provide important groundwater quality baseline information in which to help track any VRGB groundwater quality trends as the area continues its rapid residential and commercial growth.

Future groundwater quality sampling should not only resample ADEQ index wells but also attempt to sample recently-drilled wells in areas of the VRGB where previously no wells existed. This strategy would attempt to overcome perhaps the chief weakness of this study. Although a greater spatial area was covered by this ADEQ study than by previous groundwater quality studies, groundwater samples could not be collected from large areas of the VRGB that lacked wells and/or springs. Thus, specific groundwater quality information is still lacking from large areas of the VRGB.

For further information contact:

Douglas Towne
ADEQ
3033 North Central Ave #360
Phoenix, AZ 85012
1-800-234-5677 Ext 4412
towne.douglas@ev.state.az.us

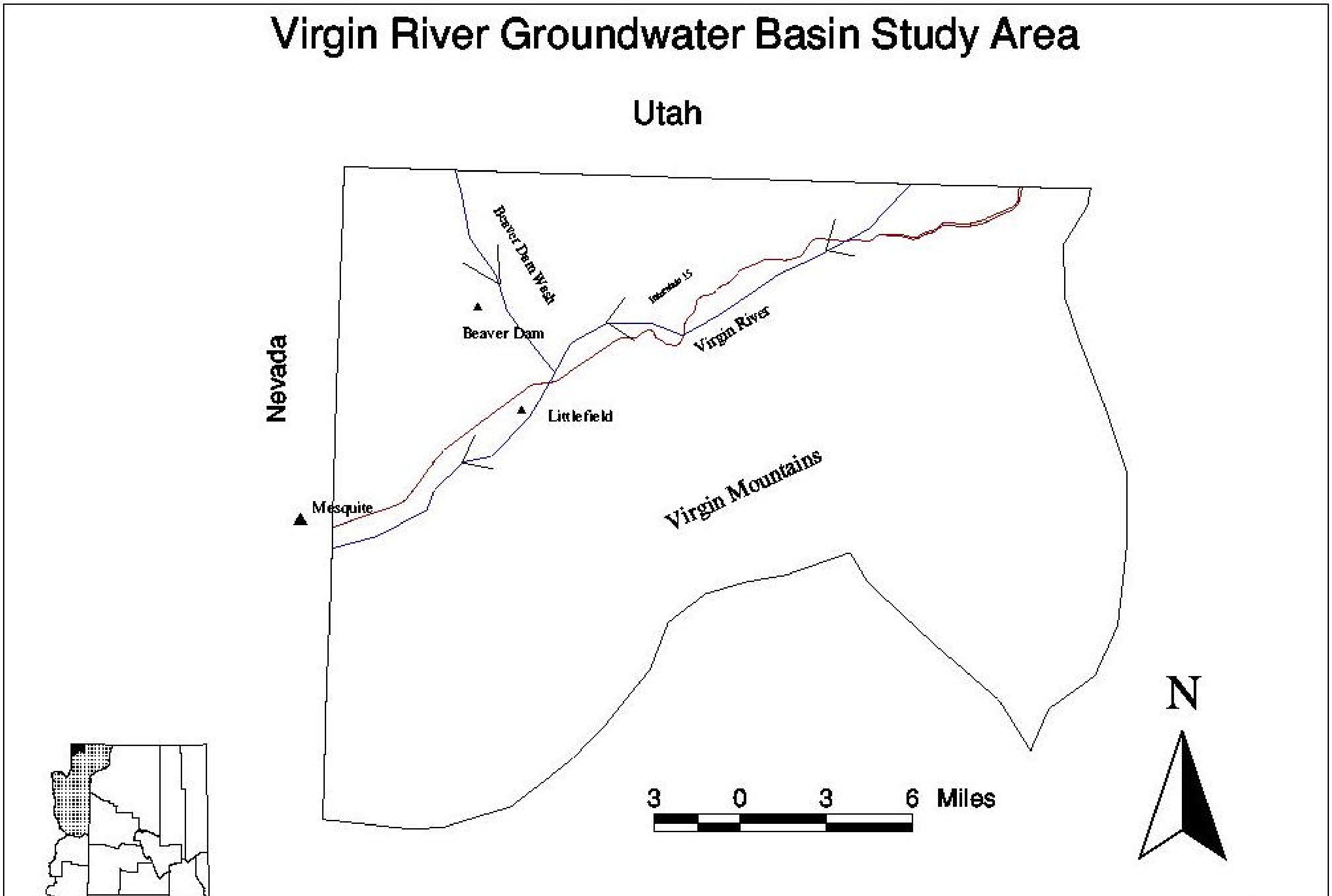

Figure 1. Location of Study Area

Figure 2. Location of VRGB Groundwater Samples

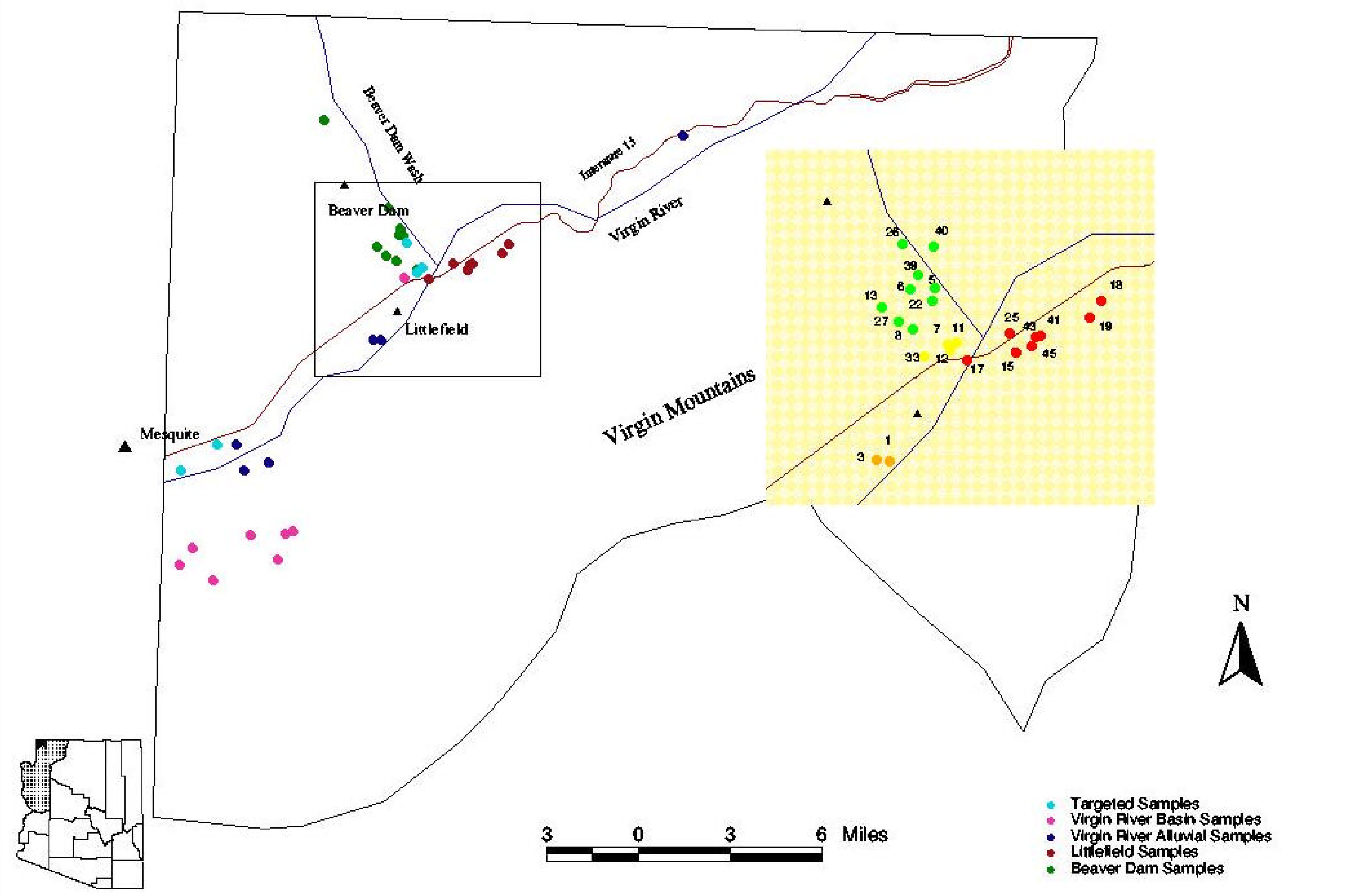

Figure 6a. TDS Levels of VRGB Groundwater Samples